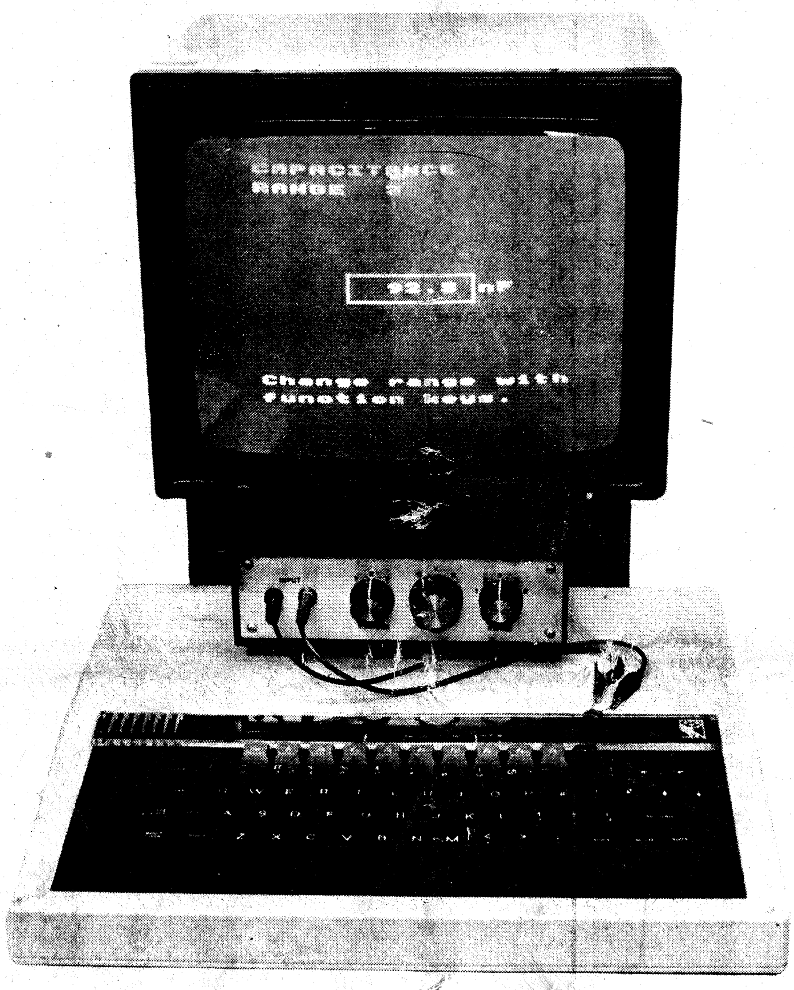
DIGITAL MULTIMETER ADD-ON FOR COMPUTERS



BY R.A. PENFOLD

IT IS NOT difficult to adapt most home-computers to measure electrical quantities, such as resistance or voltage, and it is very simple indeed in the case of a machine such as the BBC Micro model B which has a built-in analogue-to-digital converter.

The analogue-to-digital converter in the BBC model B microcomputer is not a high speed type, having a fastest sampling rate of once every 10 milliseconds with just one of the four channels in use, but measurements in electronics are often of static quantities such as the value of a resistor or capacitor, and high speed operation is by no means essential.

SPECIFICATION

This simple add-on unit enables the BBC model B microcomputer to measure d.c. voltage, resistance, and capacitance.

There are three voltage measurement ranges having full-scale values of 1, 10, and 100 volts, and there is a high input impedance of approximately 11 megohms on all ranges.

There are five resistance and five capacitance ranges with full-scale resistance values of 1kΩ, 10kΩ, 100kΩ, 1MΩ, and 10MΩ. The full-scale capacitance values are 1nF, 10nF, 100nF, 1μF, and 10μF.

The BBC model B computer has a 12-bit analogue-to-digital converter, and although problems with noise limit the resolution and accuracy to a certain extent, this still enables a reasonably high degree of accuracy to be obtained. Results are certainly more than adequate for normal requirements.

The system gives a warning if over-ranging occurs so that misleading results are avoided, but this facility is provided by the software rather than the hardware. The unit is powered from the computer and does not need any form of additional power supply.

SIMPLY PLUGS INTO THE USER AND ANALOGUE PORTS

MEASURES

Resistance (5 ranges):
1kΩ, 10kΩ, 100kΩ
1MΩ and 10MΩ
Capacitance (5 ranges):
1nF, 10nF, 100nF,
1μF and 10μF
Voltages (3 ranges):
1, 10 and 100 volts.

Software available

The computer can be used simply as a digital (or quasi analogue) readout in conjunction with a TV set or monitor, or it could be used in a more sophisticated manner.

Systems of this type can be used in checking pieces of equipment or components, with the computer indicating whether or not the results from a test or set of tests are within acceptable limits, and showing which ones the equipment under test has failed where appropriate.

Another possibility is to use the system when checking for intermittent faults, since the equipment could be programmed to monitor a strategic voltage and register any change that occurs when the fault appears.

Incidentally, the circuit can be used as a simple analogue resistance, capacitance, voltage meter if its output is connected to a 100μA meter in series with a 16kΩ resistor, and it is not only of use to BBC micro owners. However, a stabilised supply of around 5 volts to 9 volts would be required.

SYSTEM OPERATION

Fig. 1 shows the unit in block diagram form, and there are really three separate sections to the circuit. One to measure resistance, one to measure voltage, and the third to deal with capacitance measurements.

RESISTANCE

If we take the resistance section first, this consists basically of just a constant current generator and a buffer amplifier having a very high input impedance. The resistor being tested is fed with the output

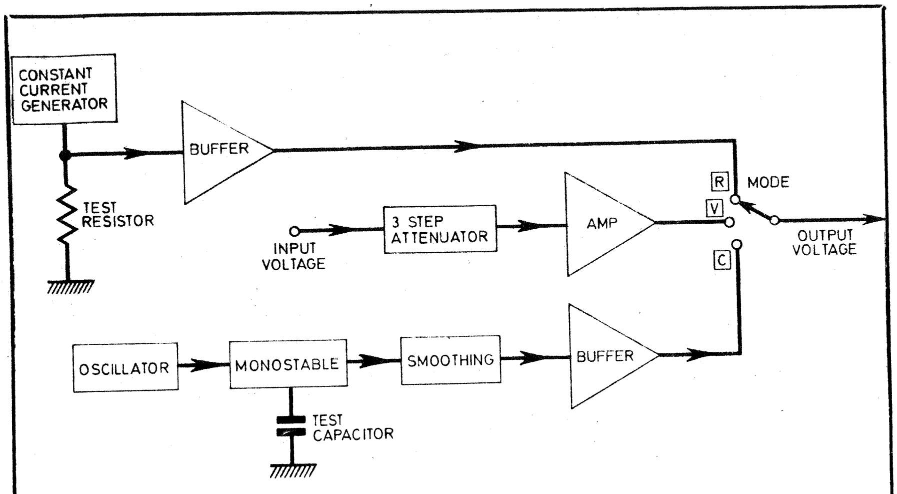


Fig. 1. Block diagram to illustrate how the system works.

from the constant current generator, and the computer monitors the voltage produced across the resistor.

The buffer amplifier ensures that no significant resistance is placed across the test resistance (which would effectively lower its value).

With the test current at a fixed value the output voltage is proportional to the test resistance, so that a linear relationship between test resistance and output voltage is produced. This is not actually essential in this application since the computer could be programmed to counteract a non-linear resistance-voltage characteristic, but this system is simple, accurate, and enables straightforward software to be employed.

VOLTAGE

For voltage measurements an amplifier having a high input resistance is used to act as a buffer ahead of the computer. This ensures that there is minimal loading on the circuit under test so that reliable readings are obtained. As the lowest voltage range has a full-scale value of 1 volt, and around 1·3 volts is needed to fully drive the analogue inputs of the computer, the amplifier provides a small amount of voltage amplification in addition to the buffering. A three-step attenuator at the input can be used to reduce the sensitivity of the circuit by a factor of 10 or 100, so that the two higher voltage ranges are produced.

CAPACITANCE

For capacitance measurement an oscillator is used to trigger a monostable multivibrator, and the test capacitor is the timing capacitance for the latter.

With the monostable triggered at a fixed rate, its average output potential depends on the pulse length produced by the test capacitance. The higher this capacitance the higher the average output voltage, and there is a linear relationship between capacitance and output potential.

The output from the monostable is, of course, a pulse signal, and in order to obtain accurate results this must be smoothed to a steady d.c. potential before it is applied to the analogue input of the computer.

A simple C-R smoothing circuit is used, followed by a buffer amplifier which gives a suitably low output impedance to drive the analogue-to-digital converter.

A three-way switch is used to select the desired circuit and couple it through to the computer.

THE CIRCUIT

Fig. 2 shows the full circuit diagram of the Digital Multimeter Add-On for the BBC Micro model B.

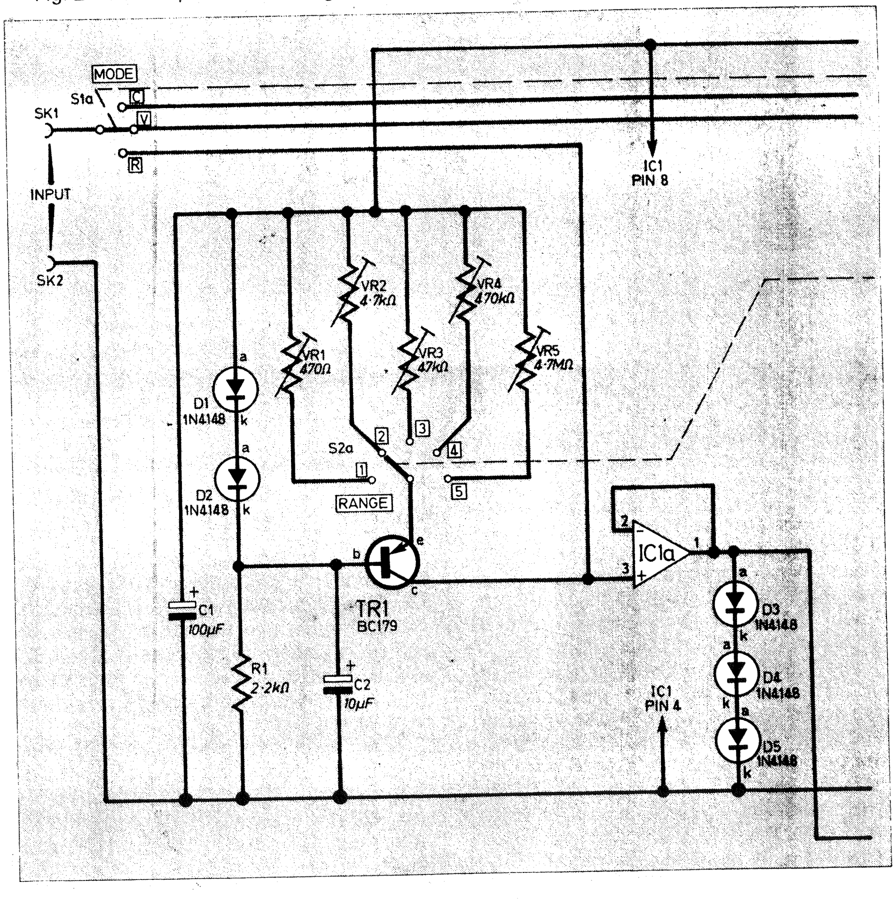
TR1 and IC1a form the basis of the resistance measurement interface. TR1 is used as a conventional single transistor constant current source having a nominal 1·3 volt forward bias fed to its base by D1, D2, and R6. This gives a potential of about 0·65 volts across whichever of the emitter resistances is switched into circuit by S2a, and an emitter current which is set by the selected resistance plus this bias voltage.

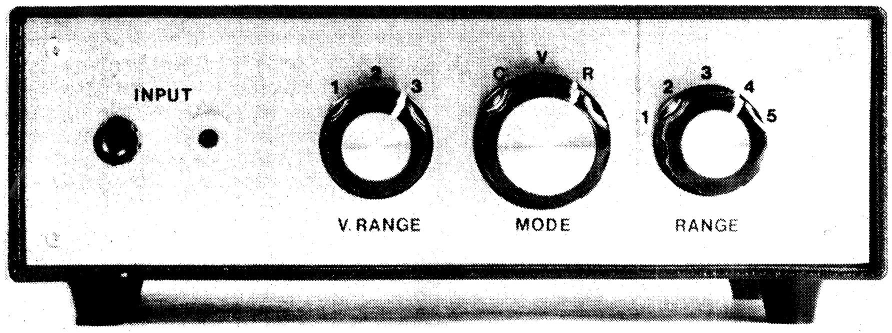
The resistor under test is connected in the collector circuit of TR1, and this will pass a current which is almost identical to TR1 emitter current, provided the resistance is not excessively high.

Having five switched emitter resistances (and test currents) gives the unit its five resistance ranges, and in practice VR1 to VR5 are adjusted to give the required full-scale values.

IC1a is the buffer amplifier, and this is an operational amplifier used in the non-inverting mode with 100 per cent negative feedback to give unity voltage gain. The CA3120E used for IC1 (and the CA3140E single amp version used for IC4) has a PMOS input stage which gives an extremely high input impedance of over 1 million megohms. This gives negligible shunting on the resistor under test and no loss of accuracy.

Fig. 2. The complete circuit diagram of the Digital Multimeter Add-On for computers.





COMPONENTS

Resistors

R1	2·2kΩ
R2	10MΩ 1% metal film 0·4W
R3	1MΩ 1% metal film 0·4W
R4	100kΩ 1% metal film 0·4W
R5	11kΩ 1% metal film 0·4W
R6	10kΩ
R7	2·7kΩ
R8	470kΩ
R9	100kΩ
R10	10MΩ 1% metal film 0·4W
R11	1MΩ 1% metal film 0·4W
R12	100kΩ 1% metal film 0·4W
R13	10kΩ 1% metal film 0·4W
R14	1kΩ
R15	3·9kΩ
R16	5·6kΩ

All $\frac{1}{4}$W carbon ±5% except where stated otherwise

COMPONENTS approximate cost £18

Potentiometers

VR1	470Ω	0·25W carbon vertical preset
VR2	4·7kΩ	
VR3	47kΩ	
VR4	470kΩ	
VR5	4·7MΩ	
VR6	4·7kΩ	0·1W horizontal carbon preset
VR7	100kΩ	0·1W horizontal carbon preset

See **Shop Talk** page 164

Capacitors

C1	100μF 10V elect. axial leads
C2,4	10μF 25V elect. axial leads (2 off)
C3	100nF polycarbonate
C4	100nF ceramic

Semiconductors

IC1	CA3240E m.o.s.f.e.t. dual op-amp
IC2	555 timer i.c.
IC3	7555 timer i.c.
IC4	CA3140E m.o.s.f.e.t. op-amp
TR1	BC179 silicon *pnp*
D1,2,3,4,5,7	1N4148 silicon signal diode (6 off)
D6	BZY88C3V9 3·9V 400mW Zener diode

Miscellaneous

PL1	15-way D-type plug (or two 1mm plugs—see text)
SK1	4mm socket (red)
SK2	4mm socket (black)
SK3	20-way i.d.c. socket
S1,3	4-pole 3-way rotary switch
S2	2-pole 6-way rotary switch with end stop at position 6

Printed circuit board: single-sided, size 150 × 38mm, *EE PCB Service*, Order code 8403-05; single-sided Veropins (24 off); control knobs with index (3 off); 20-way i.d.c. ribbon cable; screened cable; case type WB3 vinyl covered, size 203 × 127 × 51mm or similar; hook-up wire, ribbon or single; 6BA fixings: 20mm screws, nuts, shakeproof Block washers and 10mm long spacers.

CONSTRUCTION

Start by building the printed circuit board. The actual-size master pattern of this is shown in Fig. 3. This board is available from the *EE PCB Service*, Order code 8403-01. As IC1 and IC4 have PMOS input stages they should be fitted in (8-pin d.i.l.) i.c. sockets and the normal MOS handling precautions should be taken.

IC3 is a CMOS device, but due to its internal protection circuitry it does not require any special handling precautions. However, it is still probably advisable to use a socket for this device as it is not one of the cheapest integrated circuits.

Be careful to connect the integrated circuits the right way round, and note that IC3 has the opposite orientation to the other three. It is important to use the specified types of preset resistor if they are to fit onto the printed circuit board properly, and two different types are utilised in this design. Do not overlook the single link wire between IC2 and IC3. Veropins are fitted to the board at points where connections to off-board components will eventually be made, see Fig. 4.

CASE DETAILS

An instrument case measuring about 203 × 114 × 64mm was used as the case for the prototype, but this is somewhat larger than is really necessary, and a slightly smaller case could probably be used without too much difficulty. The three switches and two input sockets are mounted on the front panel of the case; rear panel is drilled to take the output lead to the analogue input of the computer.

As the output impedance of the unit is quite low it is not essential to use a screened cable here. Fig. 5(a) shows the two connections to the analogue input of the computer. These connections can be made via a 15-way D-type connector or a couple of 1mm plugs.

A rectangular hole for the ribbon cable which connects to the user port must also be made in the rear panel. On the prototype a ready-wired 20-way i.d.c. header socket and ribbon cable are used to make the connections to the user port (the 15 unused wires just being ignored), and this is probably the most simple way of making the connections. However, a home-wired 20-way i.d.c. connector and 5-way ribbon cable could be used if preferred. Fig. 5(b) shows the connections to the user port.

On the prototype the exit hole for the ribbon cable is actually a rectangular cut-out which was filled in the top of the removeable rear panel, but this is something that must be varied to suit the particular case and cable that are used.

The printed circuit board is mounted on the base panel or chassis of the case using 6BA fixings.

To complete the unit the point-to-point wiring is added, and this is shown in Fig. 4. This wiring will be more neat if ribbon cable is used, but ordinary hook-up wire is suitable.

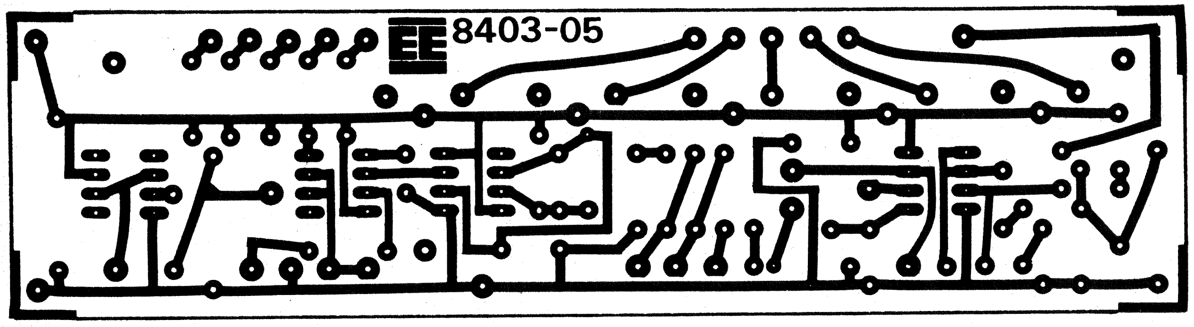


Fig. 3. The master p.c.b. pattern shown actual-size from copper track side. This board is available from the *EE PCB Service,* Order code 8403-05.

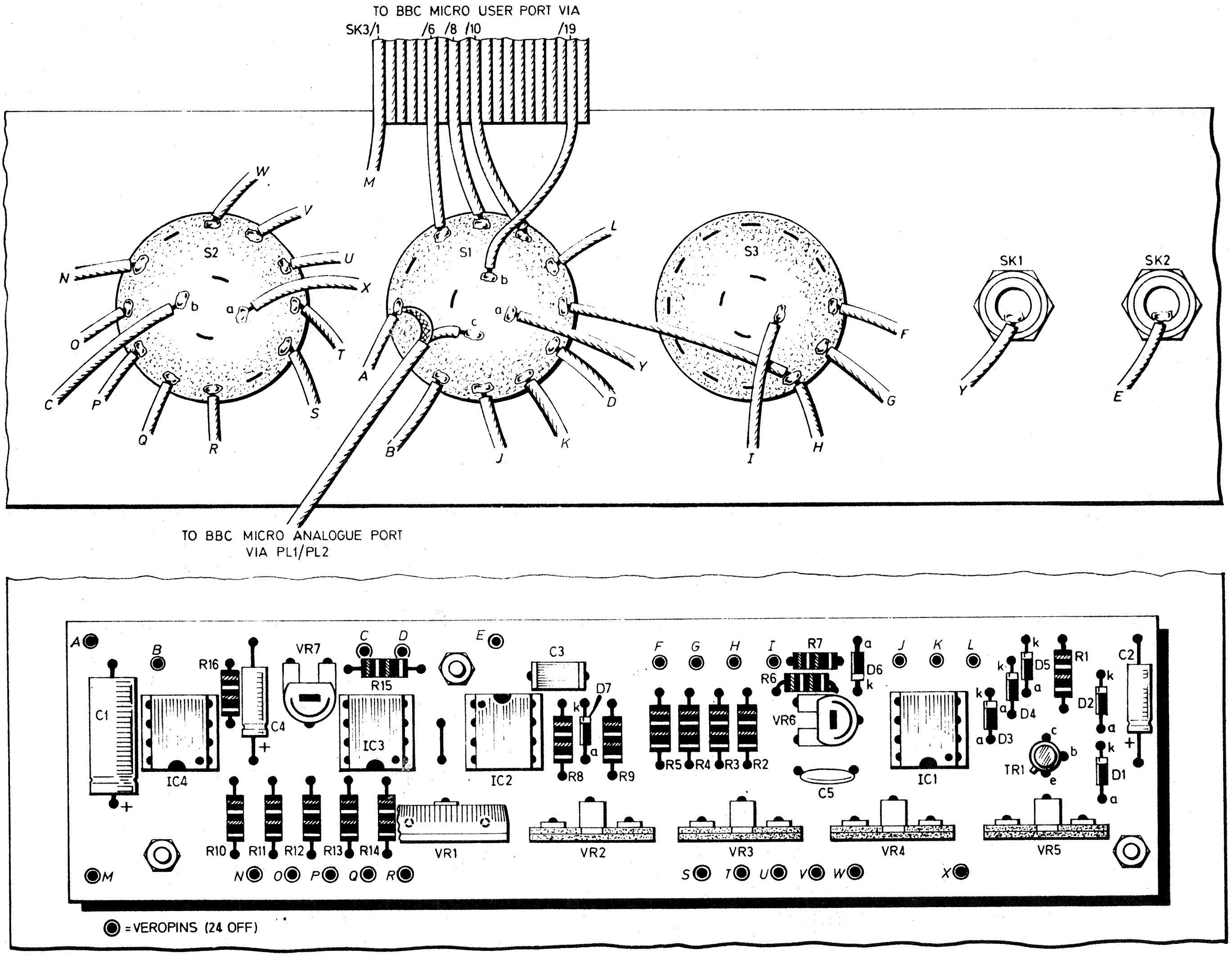


Fig. 4. Shows the layout of the components on the topside of the printed circuit board. Note that there are 24 Veropins labelled which receive the correspondingly labelled wires from the front panel mounted components, shown above.

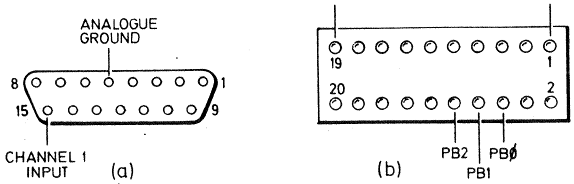


Fig. 5. Pin identification details for (a) the Analogue port and (b) the User port on the BBC Micro model B.

PROGRAM : MULTIMETER

```
10  REM MULTIMETER PROGRAM
20  REM by John Penfold
30  REM EVERYDAY ELECTRONICS
40  REM
50  MODE 2:VDU 23;1,0;0;0;0;
60  OSBYTE =&FFF4:function=0:setrange=0:range=3
70  DIM P% 60
80  [OPT 0
90  .SET
100 LDA #&97
110 LDX #&62
120 LDY #&0
130 JSR OSBYTE
140 LDA #&E1
150 LDX #160
160 LDY #&0
170 JSR OSBYTE
180 LDA #16
190 LDX #1
200 JSR OSBYTE
210 .FUNCTION
220 LDA #&96
230 LDX #&60
240 JSR OSBYTE
250 STY &70
260 RTS:]
270 CALLSET
280 VDU 23,225,0,28,54,99,99,54,99,0
290 VDU 23,226,0,0,51,51,51,18,108,96
300 PROCscreen
310 PROCmeter
320 END
330 DEF PROCscreen
340 COLOUR 132:CLS
350 GCOL 0,3
360 MOVE 440,512:DRAW 880,512:DRAW 880,600:DRAW 440,600:DRAW 440,512
370 COLOUR 0
380 PRINT TAB(2,4);"RANGE"
390 CALLFUNCTION
400 PROCchange_function
410 COLOUR 1:PRINT TAB(2,24);"Change range with"
420 PRINT TAB(2,26);"function keys."
430 ENDPROC
440 DEF PROCmeter
450 REPEAT
460   CALLFUNCTION:IF ?&70<>function THEN PROCchange_function:function=?&70
470   T=TIME
480   REPEAT
490     setrange=INKEY(0):IF setrange>160 THEN PROCchange_range(setrange)
500     current_reading=(ADVAL(1)/64-4):IF current_reading>1020 PRINT TAB(8,1
4);"*****":UNTIL FALSE
510   total=total+current_reading
520   readings=readings+1
530   UNTIL TIME>=T+40
540 average_reading=INT(total/readings)
550 IF average_reading<0 THEN average_reading=0
560 COLOUR 1:PRINT TAB(8,14);FNdisplay(average_reading,range)
570 total=0:readings=0
580 UNTIL FALSE
590 ENDPROC
600 DEF PROCchange_function
610 COLOUR 0
620 IF ?&70=251 PRINT TAB(15,14);"F":PRINT TAB(2,2);"CAPACITANCE"
630 IF ?&70=253 PRINT TAB(15,14);"V":PRINT TAB(14,14);" ":PRINT TAB(2,2);"VOL
TAGE    "
640 IF ?&70=254 PRINT TAB(15,14);CHR$(225):PRINT TAB(2,2);"RESISTANCE "
650 PRINT TAB(8,14);"      "
660 IF ?&70=253 AND range>3 THEN range=3
670 IF setrange<160 THEN setrange=range+160:PROCchange_range(setrange)
680 ENDPROC
690 DEF PROCchange_range(setrange)
700 IF setrange>155 OR (setrange>163 AND ?&70=253) THEN ENDPROC
710 range=setrange-160
720 COLOUR 0
730 PRINT TAB(9,4);range
740 IF range<4 AND ?&70=251 THEN PRINT TAB(14,14);"n"
750 IF range>=4 AND ?&70=251 THEN PRINT TAB(14,14);CHR$(226)
760 IF range<4 AND ?&70=254 THEN PRINT TAB(14,14);"K"
770 IF range>=4 AND ?&70=254 THEN PRINT TAB(14,14)"M"
780 IF ?&70=253 THEN PRINT TAB(14,14);" "
790 ENDPROC
800 DEF FNdisplay(average_reading,place)
810 display$=STR$(average_reading)
820 IF place>3 place=place-3
830 IF LEN(display$)<4-place THEN display$=STRING$((4-place)-LEN(display$),"0
")+display$
840 IF LEN(display$)=4-place THEN display$="0"+display$
850 IF LEN(display$)<4 THEN display$=STRING$(4-LEN(display$)," ")+display$
860 display$=LEFT$(display$,place)+"."+RIGHT$(display$,4-place)
870 =display$
```

Read user PORT

PROGRAM NOTES

Obviously the software must be varied to suit individual requirements, but the suggested program enables the equipment to function as a straightforward multimeter, and would make a good basis for a more specialised program.

The program reads the user port and displays the appropriate mode ("RESISTANCE", "CAPACITANCE", or "VOLTAGE") at the top of the screen provided the unit is connected.

Lines 210 to 260 read the port (in assembly language) and PROCchange-function in conjunction with PROCscreen prints the appropriate label on the screen. These also display the appropriate unit of measurement after the digital readout (with lines 280 and 290 defining two special characters for this part of the display) and draw a box around the digital readout.

PROCchange-range is used to give the correct display reading for the range in use, and function keys f1 to f5 are used to enter the appropriate range (f1 for range 1, f2 for range 2, and so on).

UPDATED DISPLAY

An infinite loop is used so that the display is being continuously updated. Due to problems with noise in the analogue-to-digital converter, rather than periodically taking and displaying a single reading from the analogue-to-digital converter a process of taking a number of readings and displaying the average is used.

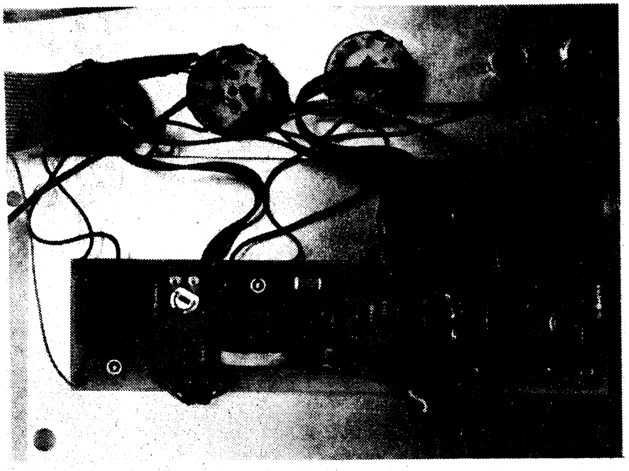
In order to obtain the fastest possible sampling rate lines 180 to 200 enable only channel 1. The reading returned by ADVAL(1) is in the range 0 to 65535, but this is divided by 64 to give a reading of between 0 and 1023. However, line 500 includes a check for overload values and these are indicated by stars in the display box.

Of course, the readout is not a straightforward 0 to 1000 reading, and operating the correct function (range) key puts the decimal point in the appropriate position. Leading zeros are suppressed incidentally, and the display is flicker free.

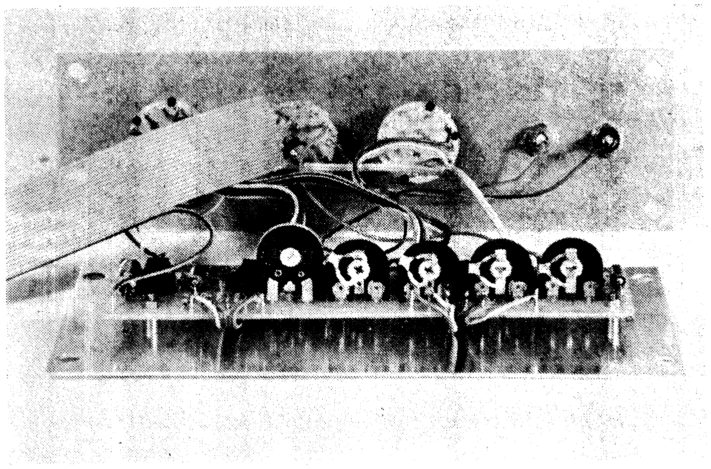
Line 50 sets the mode and switches off the cursor, but note that this VDU statement will not work with one of the early BBC model B micros if it is still fitted with O.S. 0.1.

SETTING UP

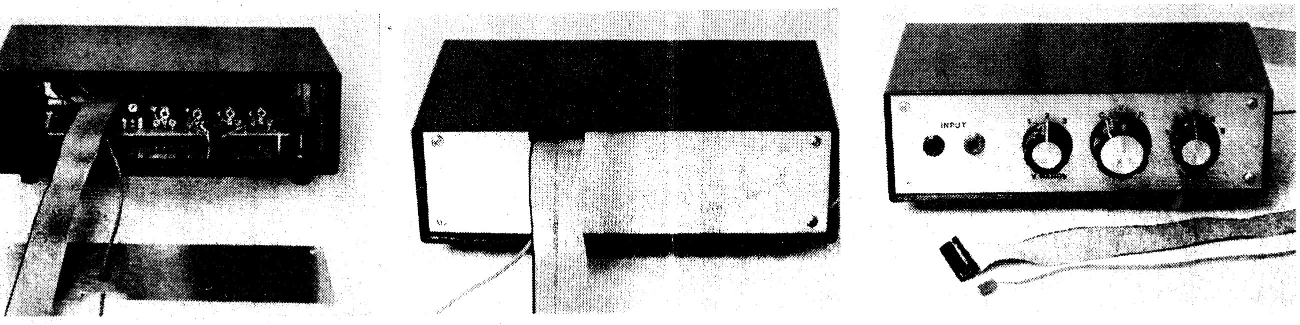
After a thorough check of the wiring, the unit is connected to the user and analogue ports of the computer, and the program "MULTIMETER" is loaded into the computer. Refer to the program



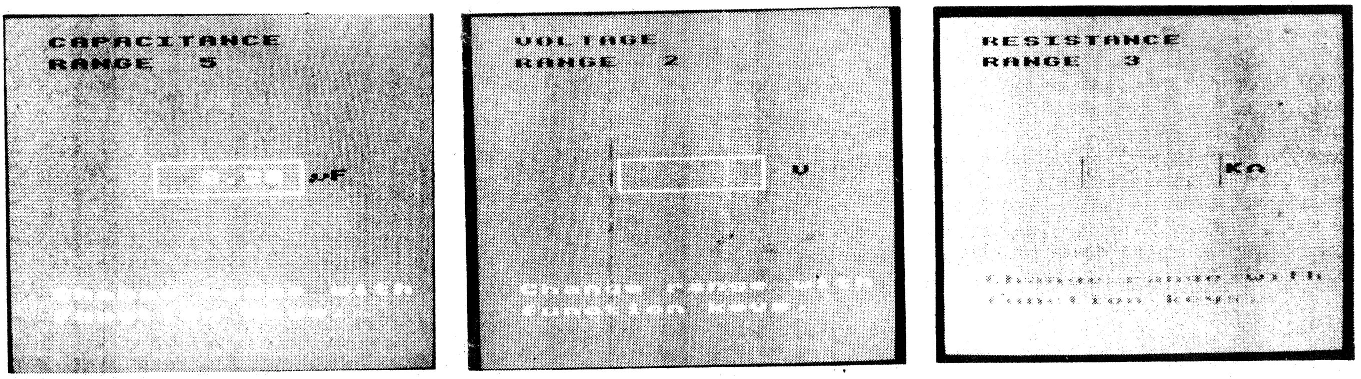
The completely assembled printed circuit board shown fitted here to the case chassis plate.



Rear view of the completed unit which has been removed from its case.



Various views of the completed prototype.



CAPACITANCE
RANGE 5
μF

VOLTAGE
RANGE 2
V
Change range with
function keys.

RESISTANCE
RANGE 3
KΩ

Screen displays for each of the three operational modes.

notes if you are uncertain about the way in which the program is used.

In order to calibrate the voltage ranges a known voltage is required, and this should correspond to between 50 per cent and 100 per cent of the full-scale reading of the range on which the unit is calibrated (it does not matter which range this is). For example, a 9-volt battery could have its actual output potential measured using a multimeter, and with the add-on switched to voltage range 2 (0V to 10V) VR6 would be adjusted to produce the correct reading on the display.

CAPACITANCE RANGE

A similar procedure is used to calibrate the capacitance ranges, but the calibration reference source is a close tolerance (1 or 2 per cent) capacitor. For instance, a 10nF 1 per cent capacitor could be used to calibrate the unit on capacitance range 2, with VR7 being adjusted to give the appropriate display reading.

Note that accuracy on range 1 is limited by stray capacitance, and a high degree of accuracy will not be obtained, especially when measuring very low value capacitors. It is thus better to calibrate the unit on one of the other four ranges.

RESISTANCE RANGE

Calibration of the resistance ranges is somewhat different in that each range is individually calibrated. This requires five 1 per cent resistors, and ideally values of 1kΩ, 10kΩ, 100kΩ, 1MΩ, and 10MΩ should be used to calibrate ranges 1 to 5 respectively. The calibration presets are VR1 and VR5 respectively.

When using the unit make sure that the mode switch is in the correct position, especially when measuring high voltages or voltages having a low impedance source. Otherwise there is a risk of the circuit being damaged. □